

Using Logistic Regression To Predict the Probability of Debris Flows Occurring in Areas Recently Burned By Wildland Fires

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Debris Flow!



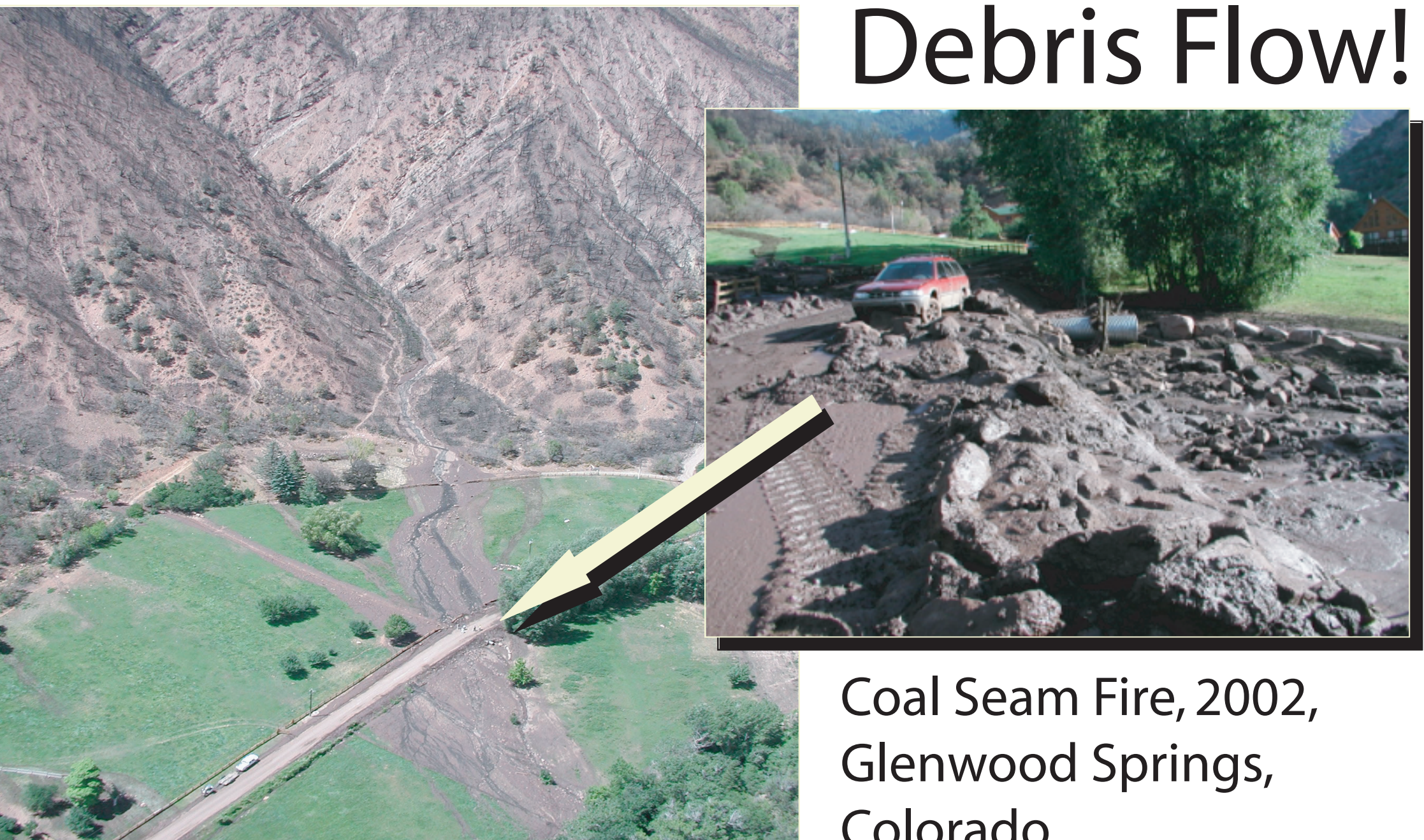
Missionary Ridge Fire, 2002, Durango, Colorado



Abstract

Logistic regression was used to predict the probability of debris flows occurring in areas recently burned by wildland fires. Multiple logistic regression is conceptually similar to multiple linear regression because statistical relations between one dependent variable and several independent variables are evaluated. In logistic regression, however, the dependent variable is transformed to a binary variable (debris flow did or did not occur), and the actual probability of the debris flow occurring is statistically modeled. Data from 399 basins located within 15 wildland fires that burned during 2000-2002 in Colorado, Idaho, Montana, and New Mexico were evaluated. More than 35 independent variables describing the burn severity, geology, land surface gradient, rainfall, and soil properties were evaluated. The models were developed as follows: (1) Basins that did and did not produce debris flows were delineated from National Elevation Data using a Geographic Information System (GIS). (2) Data describing the burn severity, geology, land surface gradient, rainfall, and soil properties were determined for each basin. These data were then downloaded to a statistics software package for analysis using logistic regression. (3) Relations between the occurrence/non-occurrence of debris flows and burn severity, geology, land surface gradient, rainfall, and soil properties were evaluated and several preliminary multivariate logistic regression models were constructed. All possible combinations of independent variables were evaluated to determine which combination produced the most effective model. The multivariate model that best predicted the occurrence of debris flows was selected. (4) The multivariate logistic regression model was entered into a GIS, and a map showing the probability of debris flows was constructed. The most effective model incorporates the percentage of each basin with slope greater than 30 percent, percentage of land burned at medium and high burn severity in each basin, particle size sorting, average storm intensity (millimeters per hour), soil organic matter content, soil permeability, and soil drainage. The results of this study demonstrate that logistic regression is a valuable tool for predicting the probability of debris flows occurring in recently-burned landscapes.

Debris Flow!



Coal Seam Fire, 2002, Glenwood Springs, Colorado

Maps predicting the probability of debris flows were developed in four steps

(1) The first step was to delineate basins that did and did not produce debris flows using National Elevation Data (NED). A total of 399 basins located within 15 wildland fires in 4 western states were delineated. As an example, basins from the Missionary Ridge Fire in Colorado are shown in figure 1.

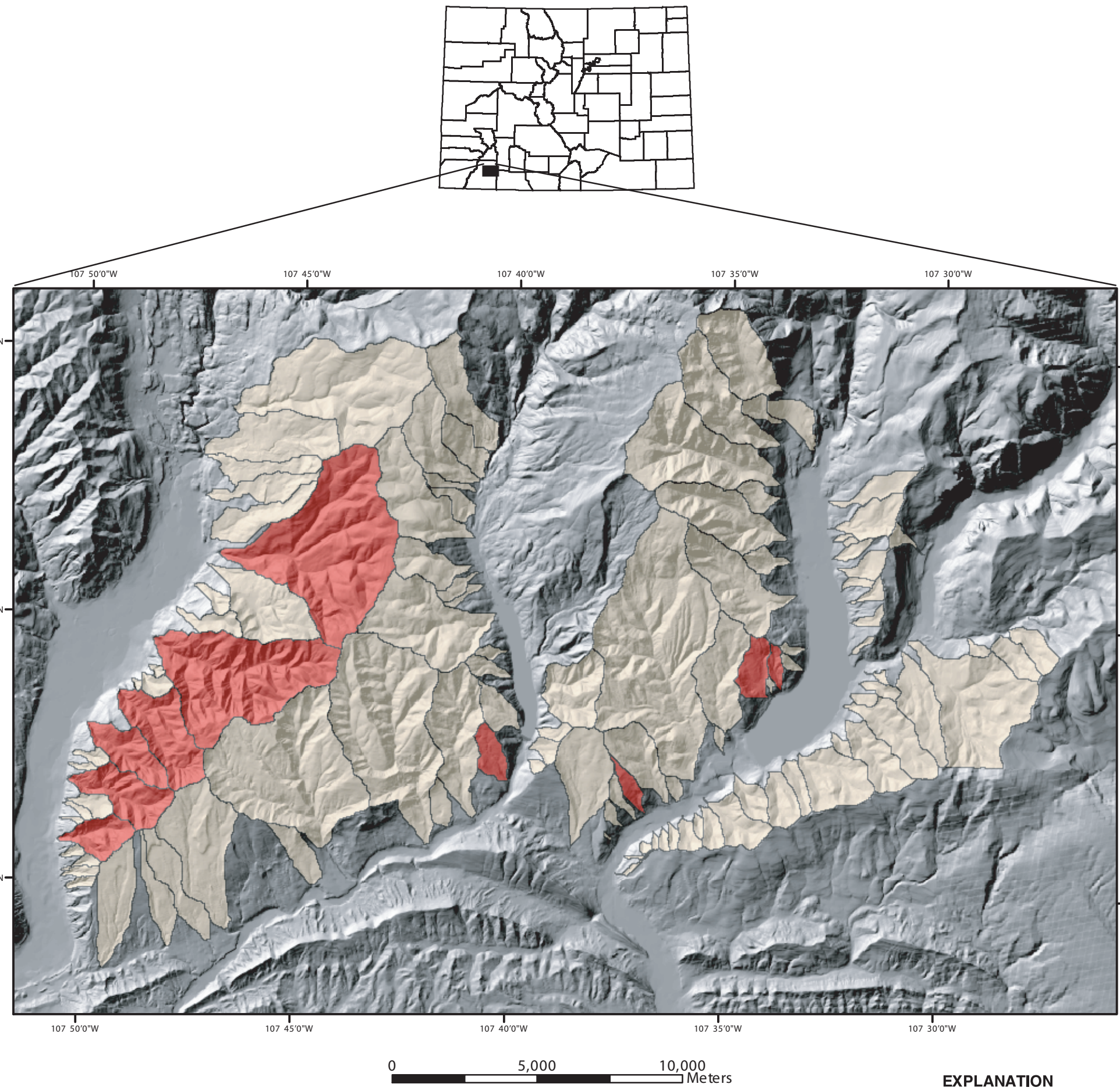


Figure 1. Basins with and without debris flows, Missionary Ridge Fire, 2002, near Durango, Colorado.

(2) The second step was to determine the burn severity (fig. 2), geology, land surface gradient, rainfall, and soil properties for each of the 15 wildland fires.

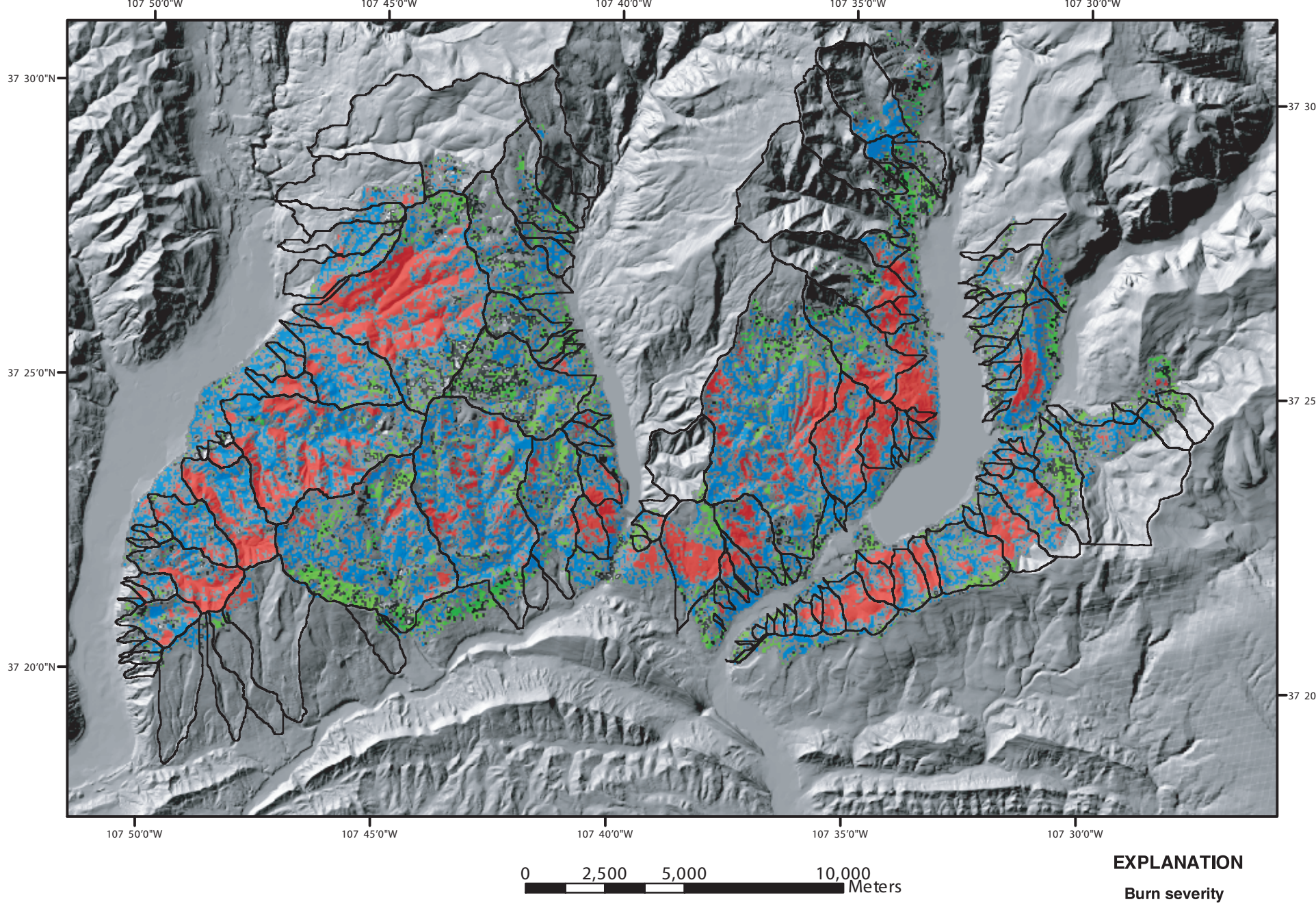


Figure 2. Burn severity at the Missionary Ridge Fire, 2002.

(3) The third step was to observe statistical correlations of data from all 15 wildland fires and build the logistic regression models (table 1) by evaluating all possible combinations of variables.

- Univariate correlations can be a good initial indicator of which independent variables might be significant in the multivariate models. Univariate correlations are usually observed first to explore the data (table 1).
- Multivariate models were constructed by evaluating every possible combination of variables shown in table 1. Several logistic regression models were constructed using different combinations of variables, and then the most effective model was selected.

Table 1. Summary of univariate and multivariate correlations between debris flow occurrence and independent variables describing burn severity, geology, land surface gradient, rainfall, soil properties, and variable interactions using data from 15 wildland fires in Colorado, Idaho, Montana, and New Mexico, 2000-2002.

[GE, greater than or equal to; mm, millimeters; hr, hour; >, greater than; <, less than; X, denotes statistically significant variable in multivariate correlations]

VARIABLES EVALUATED BY THIS STUDY	UNIVARIATE CORRELATIONS	MULTIVARIATE CORRELATIONS (in decreasing order of significance. Significant variables denoted with an X)									
		Model Number	M1	M2	M3	M4	M5	M6	M7		
		Spearman's Rho (a)	0.531	0.529	0.527	0.522	0.488	0.480	0.479		
		Wilcoxon Test (b)	0.000 <td>0.000<td>0.000<td>0.000<td>0.000<td>0.000<td>0.000<td></td></td></td></td></td></td></td>	0.000 <td>0.000<td>0.000<td>0.000<td>0.000<td>0.000<td></td></td></td></td></td></td>	0.000 <td>0.000<td>0.000<td>0.000<td>0.000<td></td></td></td></td></td>	0.000 <td>0.000<td>0.000<td>0.000<td></td></td></td></td>	0.000 <td>0.000<td>0.000<td></td></td></td>	0.000 <td>0.000<td></td></td>	0.000 <td></td>		
		McFadden's Rho (c)	0.367 <td>0.377<td>0.367<td>0.311<td>0.298<td>0.280<td>0.293</td><td></td></td></td></td></td></td>	0.377 <td>0.367<td>0.311<td>0.298<td>0.280<td>0.293</td><td></td></td></td></td></td>	0.367 <td>0.311<td>0.298<td>0.280<td>0.293</td><td></td></td></td></td>	0.311 <td>0.298<td>0.280<td>0.293</td><td></td></td></td>	0.298 <td>0.280<td>0.293</td><td></td></td>	0.280 <td>0.293</td> <td></td>	0.293		
BURN SEVERITY	Spearman's Rho (a)	McFadden's Rho (c)									
Percent of Total Area in Each Basin That Was Burned at Low Severity	-0.352	0.000									
Percent of Total Burned Area in Each Basin That Was Burned at Low Severity	-0.400	0.123									
Percent of Total Area in Each Basin That Was Burned at Medium Severity	0.185	0.008									
Percent of Total Burned Area in Each Basin That Was Burned at Medium Severity	0.080	0.003									
Percent of Total Area in Each Basin That Was Burned at High Severity	0.193	0.014									
Percent of Total Burned Area in Each Basin That Was Burned at High Severity	0.166	0.051									
Percent of Total Area in Each Basin That Was Burned at Medium Plus High Severity	0.416	0.043				X					
Percent of Total Burned Area in Each Basin That Was Burned at Medium Plus High Severity	0.396	0.103				X	X	X		X	
Percent of Total Area Burned at All Severities	0.065	0.022									
GEOLOGY											
Sedimentary	-0.218	0.000									
Granitic	0.022	0.000									
Metamorphic	0.116	0.017									
Volcanic	0.225	0.042									
LAND SURFACE GRADIENT											
Average Gradient (percent)	0.054	0.013									
Gradient Times Total Area	-0.030	0.006									
Gradient Divided by Total Area	0.024	0.006									
Percent Total Basin Area with Slopes GE 30 percent	-0.058	0.007			X	X	X	X		X	
Percent Total Basin Area with Slopes GE 50 percent	0.069	0.023									
Average aspect (degrees from north)	-0.062	0.000									
Ruggedness (change in basin elevation/square-root of area)	0.281	0.035								X	
RAINFALL											
Storm Total (mm)	0.099	0.021						X			
Storm Duration (hr)	0.281	0.030									
Average Storm Intensity (mm/hr)	0.057	0.011			X	X	X		X	X	
Peak 10-minute Rainfall Intensity for a Given Storm (mm/hr)	0.317	0.018									
Peak 15-minute Rainfall Intensity for a Given Storm (mm/hr)	0.222	0.038								X	
Peak 30-minute Rainfall Intensity for a Given Storm (mm/hr)	0.235	0.022						X			
Peak 60-minute Rainfall Intensity for a Given Storm (mm/hr)	0.248	0.035									
SOILS PROPERTIES											
Median Particle Size (phi units)	0.386	0.024									
Mean Particle Size (phi units)	-0.176	0.029									
Particle Size Sorting	-0.196	0.050			X				X	X	
Particle Size Skewness	0.258	0.004									
Available Water Capacity (inches per inch)	0.046	0.006					X				
Clay Content (percent of material < 2mm)	-0.163	0.000				X	X	X	X	X	
Soil Erodibility Factor (KFFACT, 1 = easily eroded, 0.01 = non erosive)	-0.074	0.028									
Organic Matter (percent by weight)	-0.172	0.006			X	X	X	X	X	X	
Permeability (inches per hr)	-0.118	0.004			X	X	X	X	X	X	
Soil Thickness (inches)	-0.147	0.020			X	X	X	X	X	X	
Hydrologic Group (1 through 4, with 1 having highest infiltration)	-0.111	0.022			X	X	X	X	X	X	
Drainage (1 through 7, with 1 having highest drainage)	-0.198	0.006			X	X	X	X	X	X	
Slope (in percent)	-0.068	0.004									
Liquid Limit (percent moisture by weight)	0.046	0.004				X	X	X			
Hydric Capacity (used to identify wetlands, proportion of map unit with saturated (anaerobic) soils)	-0.190	0.002									
Annual Flood Frequency (1 to 4, 1 > 50 percent, 2 = 5 to 50 percent, 3 = 0 to 5 percent, 4 = none)	-0.005	0.003				X	X	X			
VARIABLE INTERACTIONS											
Percent of Total Burned Area in Each Basin That Was Burned at Medium Plus High Severity * Soil	n/a	n/a			X	X	X				
Organic Matter	n/a	n/a									
Sorting*Drainage	n/a	n/a			X	X	X				
Percent Slope GE 30% * Average Storm Intensity	n/a	n/a			X	X	X				
Soil Permeability * Soil Drainage	n/a	n/a				X	X				

- (a) Spearman's rho is a nonparametric rank-order test, similar to the student's t-test. Variables and models with no correlation with debris flows have spearman's rho numbers near zero, and variables with perfect correlations have numbers near plus or minus one.
- (b) The Wilcoxon test is a nonparametric test to determine if there is a significant difference between areas with and without debris flows. As the effectiveness of the models improves, the Wilcoxon p-values approach zero.
- (c) McFadden's rho is calculated by logistic regression, and conceptually is similar to an r-squared in linear regression. A McFadden's rho value of zero means there is no correlation; values between 0.2 and 0.4 denote significant correlation.

(4) The fourth step was to enter the most effective model into the GIS, and construct maps predicting the probability of debris flows occurring. As an example, the probability of debris flows occurring in the Missionary Ridge Fire is shown in figure 3.

Probability of Debris Flow = $\frac{e^{(-29.693 + 2.864*SL + 10.697*BS - 9.875*SO + 0.208*SI + 5.729*OM - 0.957*P + 9.351*D - 8.335*BS*OM + 4.669*SO*D - 0.174*SL*SI)}}{1 + e^{(-29.693 + 2.864*SL + 10.697*BS - 9.875*SO + 0.208*SI + 5.729*OM - 0.957*P + 9.351*D - 8.335*BS*OM + 4.669*SO*D - 0.174*SL*SI)}}$

Where:

- SL = Percent of basin with slope greater than or equal to 30 percent
- BS = Burn severity category
- SO = Partical size sorting, in Phi units
- SI = Average storm intensity, in millimeters per hour
- OM = Soil organic matter, in percent by weight
- P = Soil permeability, in inches per hour
- D = Soil drainage category

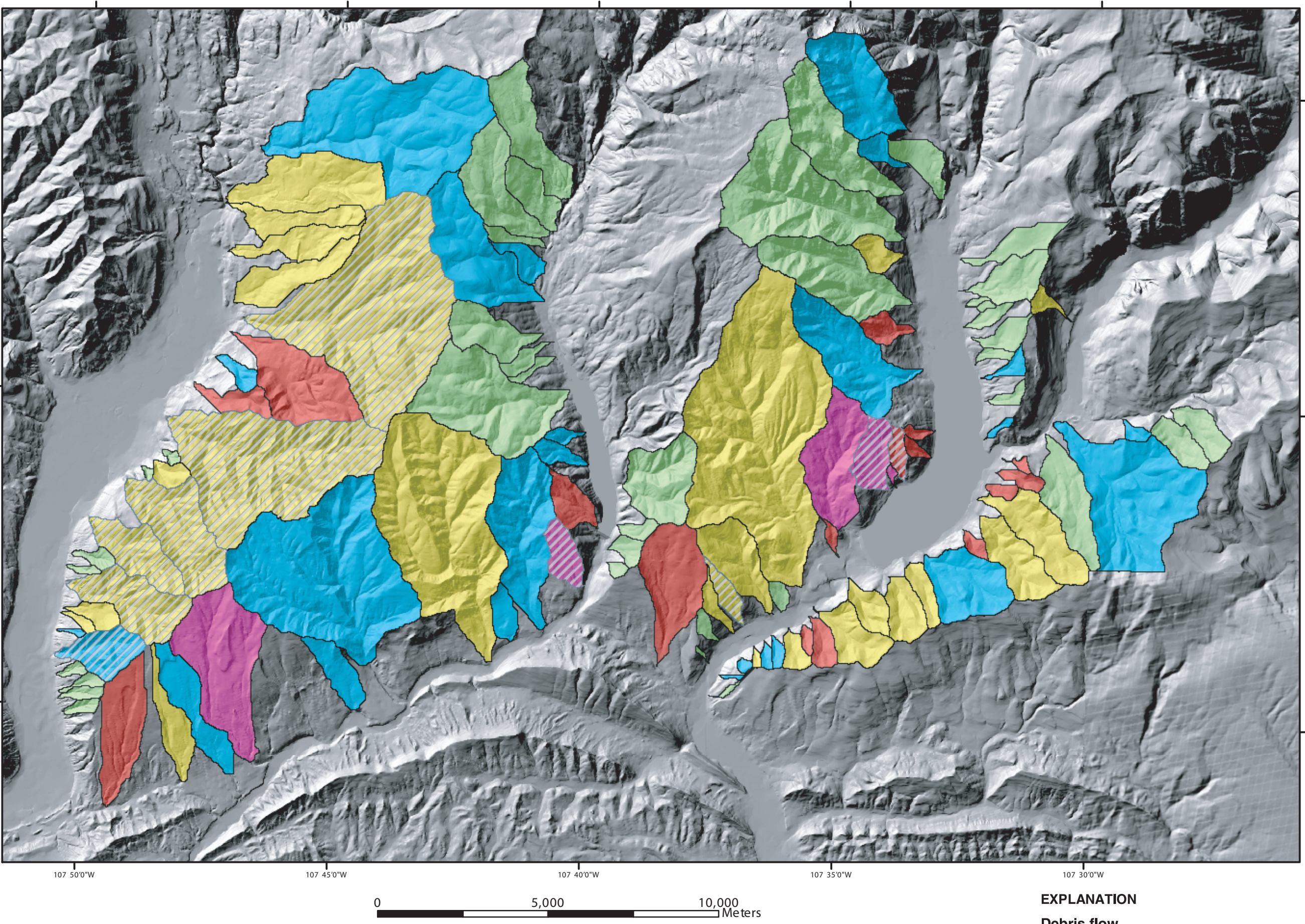


Figure 3. Probability of a debris flow occurring in response to a 25-year rain event (33 mm in one hour), Missionary Ridge Fire, 2002, using model M1.

References

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Schwarz, G.E. and Alexander, R.B. 1995, State Soil Geographic (STATSGO) Data base for the conterminous United States: U.S. Geological Survey Open-File Report 95-449, <http://water.usgs.gov/lookup/getspatial?ussoils>

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